

Heavy-Duty Vehicle Emissions Reductions Through Hybrid-Electric Drive Technology

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BACKGROUND

- **ISE Research-ThunderVolt supplies hybrid-electric drive systems for heavy-duty trucks and buses**
 - “Series’ hybrid configuration: engine only generates electricity
 - Deep-cycle battery pack improves engine efficiency
 - Accessories (power steering, braking, A/C) are electrically-driven
 - Advanced network control architecture optimizes performance
- **Demonstrated benefits of ISE advanced series hybrid systems**
 - Better fuel economy (sometimes >2x conventional vehicles)
 - Improved performance (acceleration, smoothness, less noise)
 - Reduced emissions, especially when the system is used with an alternative fuel engine (including gasoline)

FIRST GASOLINE HYBRID TRANSIT BUS



- Ford V-10 ULEV-rated engine
- Runs on standard gasoline
- Deep-cycle battery pack
- Siemens electric drive
- Low floor 40' New Flyer bus
- First bus in service - Omnitrans

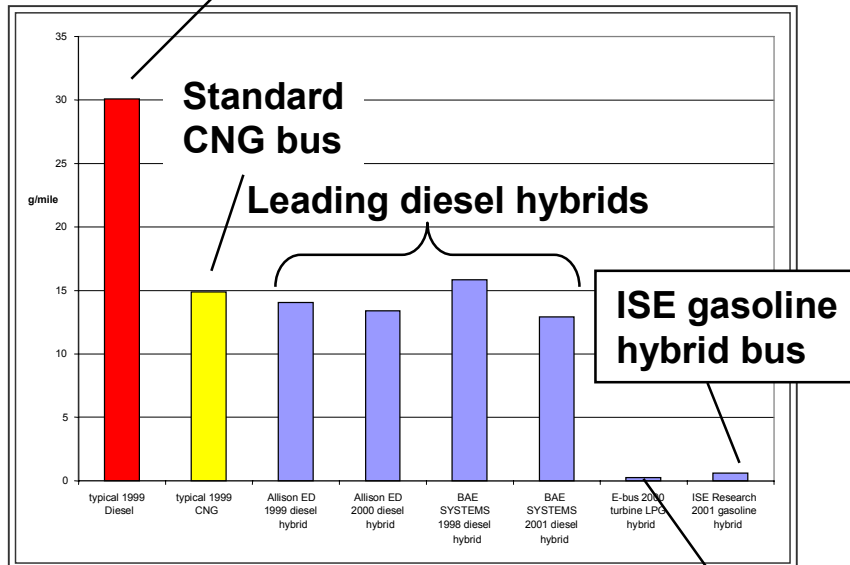
First large scale order approved by Long Beach Transit, April 2003

GASOLINE HYBRID EMISSIONS VS. CURRENT ALTERNATIVES

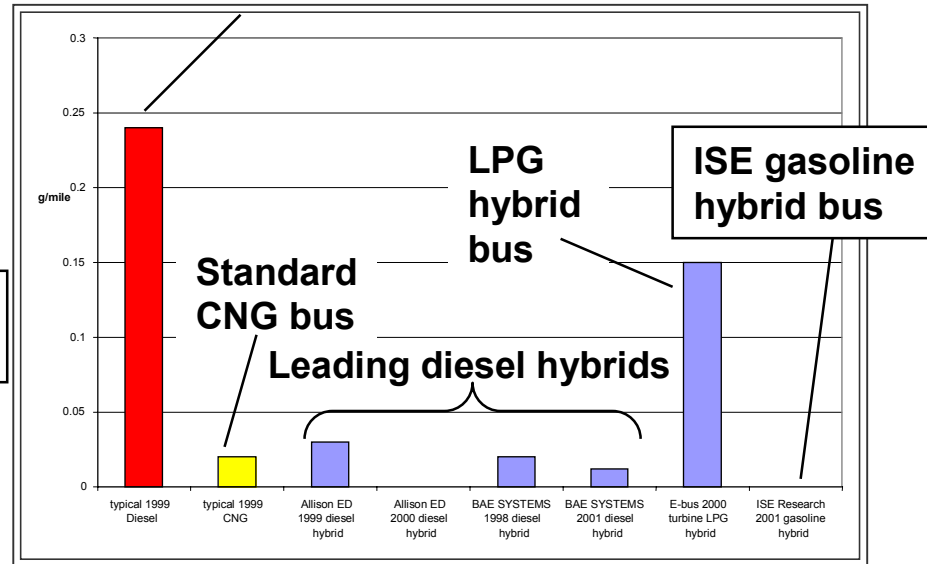
NOx Emissions

PM Emissions

Standard diesel bus



Standard diesel bus



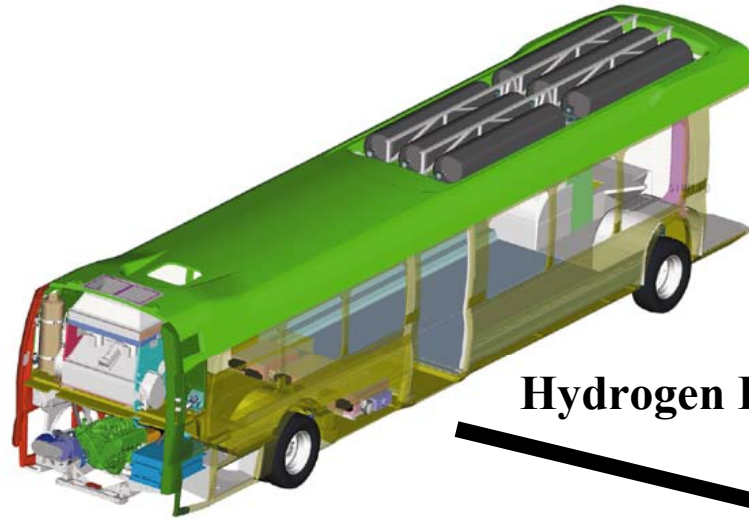
LPG hybrid bus

FIRST FUEL CELL HYBRID BUS

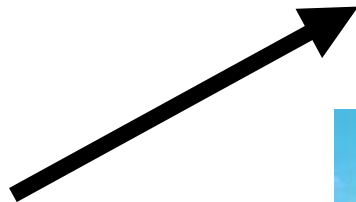
- Joint venture between ISE and Thor Industries
- UTC Fuel Cells 60kW PEM fuel cell
- Fuel cell subsystem operates at over 50% net efficiency
- Battery hybrid drive system improves efficiency by about 30%
- Demonstrated in revenue service at SunLine Transit
- Achieves 7-11 mpg (9.8 mpg average in 6-month trial)



HYDROGEN ICE HYBRID TECHNOLOGY: A BRIDGE TO FUEL CELLS



Hydrogen Hybrid Bus



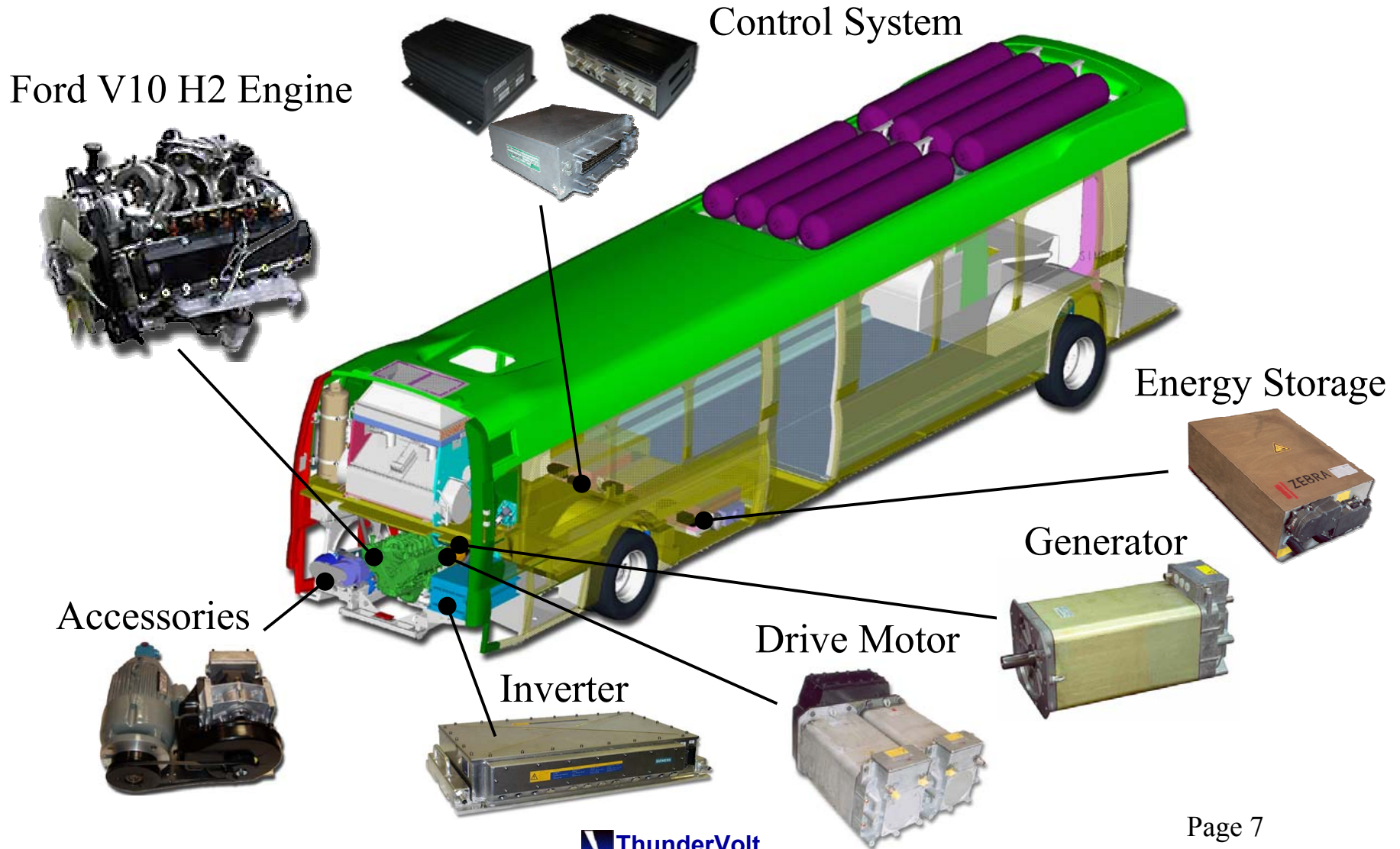
Gasoline Hybrid Bus



Fuel Cell Bus



HYDROGEN-ICE HYBRID BUS CONFIGURATION



DRIVE TECHNOLOGY RANKINGS

Option \ Rating	NOx (g/mi)	PM (g/mi)	CO2 (g/mi)	Efficiency	Average
Conventional Diesel	30	0.25	2500	33-35%	Poor
Conventional CNG	15	0.02	2400	26-28%	Poor
Diesel Hybrid	15	0.02	2400	40-42%	Poor
Advanced Hybrid Diesel	1-5	0.02	2400	40-42%	Good
CNG Hybrid	1	0.001	2300	31-33%	Good
Gasoline Hybrid	0.5	0	2300	33-35%	Good
Hydrogen ICE Hybrid*	0.5	0	0	40-42%	Excellent
Conventional Fuel Cell	0	0	0	45-55%	Excellent
Fuel Cell Hybrid	0	0	0	50-60%	Excellent

* Dependent on how engine is configured and operated

THE “WHOLE EARTH CYCLE:” CLEAN AIR AND ENERGY INDEPENDENCE



CONCLUSIONS

- **Hybrid-electric drive offers many paths to cleaner air**
 - Diesel Hybrids: high performance and low cost
 - CNG Hybrids: Low emissions
 - Gasoline Hybrids: Lower emissions and low cost
 - Hydrogen-ICE Hybrids: Near-zero emissions and available soon
 - Hydrogen Fuel Cell Hybrids: Long term zero emissions solution
- **Variety of hybrid options should suit every need**
 - Constrained budgets
 - Existing fuel infrastructure
 - Need for maximum performance
 - Need for maximum emissions reduction